Environmental Effects of Underground Salt Mining and Mine Collapses with Emphasis on the Retsof Salt Mine Livingston County, New York

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Jason M. Occhioni
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Approved By:

Dr. Garry D. McKenzie

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Abstract

Mining and mineral resources have been an important part in the history of civilizations and the Retsof Salt Mine was once one of the largest operations in underground salt mining in the world. The mine produced millions of tons of rock salt throughout its one hundred and ten year lifetime up to its collapse and flooding in 1994. Factors that have contributed to the environmental changes in the region and to the collapse include ground water flow and degradation, land subsidence, damages to properties and land and transportation problems due to damage to the infrastructure. Certain precursors have been examined prior to the collapse, but nothing prominent enough to fix or prevent. In this paper I will examine causes and effects and environmental factors of underground salt mining with emphasis on the Retsof Salt Mine and its collapse effect on the town of York, New York.

INTRODUCTION

Mineral resources and mining have been an integral part of modern civilizations throughout the world. Different cultures have depended on native natural resources that tie to that region for goods and economic privileges such as the gold rush out west in California and coal mining in the Appalachian Mountains. The United States is rich in various natural resources such as gold, copper, coal and many others. Salt mining has also been a major industry in North America, and the Retsof Salt Mine located in Livingston County, New York was once one of the largest operating salt mines in North America. Salt mines are also prominent in the Middle East, in areas such as Pakistan, Bosnia also in Austria, and Germany. Canada currently has the world's largest operating salt mine in Goderich, Ontario which covers an area of one and a half miles long and two miles wide. Salt mining is also a major industry in Detroit, Michigan and Avery Island, Louisiana. The Retsof Salt Mine, later to be owned by Akzo-Nobel, located in the town of York, New York (Figure 2), was considered to be the largest operating salt mine in the United States until its collapse and flooding on March 12, 1994 (Kappel, 1999). The collapse was associated with an earthquake (Richter magnitude, 3.6). Officials had discovered that a 500- by 500- foot section in the overlying Vernon shale roof rock had collapsed causing a huge surge of water to flow into the mine. Specific causes of the collapse are still unclear and several hypotheses including pillar use and or natural brine deposits have been presented; however, none completely confirmed. Collapse of the Retsof Salt Mine has had environmental and economical implications which include ground water quality and land subsidence in the area. Economic issues with pumping saturated ground water from the collapsed cavity and also loss of jobs for mine crews greatly affected Livingston Country and especially the town of Retsof.

This paper will investigate the causes and effects associated with the collapse of the Retsof Salt Mine to help provide a better understanding of future problems and implications of living over a collapsed mining cavity now filled with saline saturated water and brine. As noted, such problems include ground water problems and various land subsidence along with other natural hazards.

A BRIEF HISTORY OF MINING

Salt mining prior to the internal combustion engine and large material moving machines was one of the most expensive and dangerous operations for natural resources. In the beginning workers would move salt along rails pulled by mules. During the late 18^{th} century Massachusetts along with Canada and Central New York were the major players in the salt mining industry. Massachusetts being the major supplier to New York City because of its easily assessable water ways, it was not until Joshua Foreman of the New York State Assembly submitted a consideration for a canal that would connect New York City and the Atlantic Ocean with the western part of New York State. In 1825 the last section of the Erie Canal had been completed and provided a waterway for mass transport of salt and other goods was finally ready (Kurlansky, 2002). Salt findings from various well drillings and bore holes in the Genesee Valley / Retsof area were first prominent in the early 1800's but nothing transpired from that knowledge. Most of the major salt exports were coming from Syracuse and from Canada. Mining in the Genesee Valley began in the late 1880's when Caroll Coker, a geologist, raised awareness of salt deposits in the Retsof area and managed a group of capitalists to sink various wells to find the best area for a mine shaft. In 1884 on Joseph D. Lewis' farm, the first shaft was started with a hole 12 x 18 feet. The Empire Salt Company was reorganized with the completion of the "Eureka Shaft" in October of 1885 and renamed the Retsof Mining Company in honor of the first president of the company William Foster Jr. after its restructuring. Retsof comes from his name written backwards. The Retsof Mining Company excavated the shaft to mine salt 900 feet below the earth's surface. With the sinking of the Retsof Shaft, the economic boom of western New York and the Genesee Valley began to flourish and the village of Retsof was founded close to half mile from the original shaft.

EARLY SETTLEMENT IN RETSOF, NY

Approximately twenty employees were the first to settle in the town of Retsof, most of whom were of Italian background. At this time there were no houses or dwellings with minor exceptions of a few large shanties which contained a couple of rooms each. In 1886, the company built fifteen houses and a boarding house for its employees. As production increased, more labor was needed and acquired. By 1902 approximately forty houses and a boarding house along with a 1,000,000 gallon water reservoir were erected in an area known as "Little Italy" just west of the Genesee & Wyoming railroad tracks. "New Retsof" as known to early settlers was constructed shortly after this time. As population continued to grow, and just east of the Genesee & Wyoming railroad tracks, approximately twenty more houses including two boarding houses, company store, post office and a schoolhouse were built.

The development of the mine was reported in logs from the Livingston Republican, a local newspaper that followed the excavation process and would often document any advances or problems that the mine experienced. In the process of digging the shaft, a bed of gypsum, 28ft thick at 580 feet depth and pure white in most places was found on May 7, 1885. On August 20th, 1885 at approximately 905 feet below the surface, after passing through intermittent salt deposits in beds; the miners reached the first complete salt bed (23 feet thick). At 1,050 feet another salt bed approximately sixty feet thick, was found.

On November 11, 1886, it is stated that the Retsof Mining Company accepted a major contract to supply over 500,000 tons of salt to various parties. And with an engine ran hoist system, working day and night, the mine could produce 1,260 tons of salt each day. Throughout its existence, the Retsof mine spanned nearly 6,000 acres and was situated approximately 1,100 feet in the subsurface. The Retsof Salt Company was a major contributor to Livingston County's economy supplying nearly 325 jobs and generating gross sales of nearly 70 million dollars towards the end of its career. Prior to its collapse Retsof Mine Company also distributed an excess of 11 million dollars in annual payroll for its employees (Kappel, 1999).

In the beginning of this major salt mining industry, several strikes had risen in the first few decades of mining due to lack of wages and benefits after the founding of the Salt and Rock Miners union. Theses strikes occurred in July of 1900 and in March of 1917 due to lack of wages. In 1917, workers received a ten percent raise to end the strike, which raised pay to $2.20 a day (Yasso, 1987).

Underground mining is very a dangerous job, and in the lifetime of the Retsof Salt mine, there have been twenty-eight recorded deaths dating back to 1892 with the first.

The last death was recorded in 1979, and succeeding the publication of The History of Retsof, New York a fatal small roof collapse that killed one in 1990 (Yasso, 1987).

GENESEE VALLEY GEOLOGIC SETTING

The Genesee Valley has been formed through several complex geologic processes, which include: (1) tectonic uplift of Paleozoic sedimentary rocks and subsequent fluvial down cutting, (2) glaciations that resulted in erosion of bedrock and subsequent deposition as much as 750ft of glacial sediments; and (3) erosion and deposition by postglacial streams (Yager, 2001) . The Genesee Valley spans through western New York north to south from Avon, NY to Dansville, NY, including the Canaseraga Creek up through its mergence with Genesee River. A detailed section from Paleozoic rocks and younger have been recorded in the Genesee River Valley (Figure 4); however, detailed analysis of glacial sediments and till are still somewhat scarce. The Retsof Salt bed lies within the Silurian as part of the Salina group in the Vernon shale member (Figure 4). The Vernon shale consists of shale, interbedded grey to brown and green. The salt layer is approximately 13 to 30 feet thick (Yager, 2001) with a second layer approximately 60 feet. The Salina group is broken into three other members who include from oldest to youngest: Syracuse Formation, Camillus Shale and the Bertie Limestone. The Syracuse Formation consists of mostly dolomitic shale and shale interbedded with salt and some anhydrite precipitation lenses. The Syracuse Formation can also include some gypsum deposits as well. The Camillus Shale contains primarily shale but it includes some dolomite and evaporite beds (Yager, 2001).

The Bertie Limestone consists mostly of shale and dolomite with some minor limestone, despite the name. It is overlain by an unconformity with the Onondaga Limestone, one of the most recognizable units in the Genesee Valley; this member consists primarily of limestone but does have layers of 50 percent insoluble hard chert. The Onondaga Limestone is typically gray with massive bedding and often contains abundant chert. The Onondaga Limestone is of Devonian age and having such hard nature and erosion-resistant chert; it is the major aquifer throughout the Genesee Valley (Yager, 2001). The Marcellus Shale and Skaneateles shale are part of the Hamilton group with interbedded shale with some limestone with the upper half having a grey to black shale with some limestone interbedded. The Hamilton group of the Devonian shale is capped by the Moscow Shale which is approximately 120 feet thick and consists of shale and siltstone and the Tichenor Limestone at the base of the unit, an eight foot thick limestone bed. Devonian shale's are the youngest type rocks in the Genesee System, surficial deposits of sand, gravel and glacial till from the Wisconsin deglaciation along with alluvial deposits are the primary surface materials (Yager, 2001).

GLACIAL SETTING

The rest of the material overlying the Genesee Valley is a load of mostly unconsolidated glacial sediments that reach almost 750 feet below the surface; these sediments include gravel, sand, silt and clays. These sediments were deposited during the middle and late Wisconsin deglaciation and filled the pre-existing valley. End moraines consisting of glacial debris were deposited in lobes to the south of the slowly retreating glacier. As the glacier had scoured through the valley, carving out bedrock and accumulating sediment, the valley walls had been cut out to form pro-glacial lakes which existed throughout most of the glaciations. These glacial lakes included large sized boulders and cobbles, and accumulated sediment from the Genesee River and Canaseraga Creek which were draining into these glacial lakes. The final pro-glacial lake formed as the Fowlerville end moraine was deposited. The Fowlerville end moraine extends approximately 4.5 to 8 miles north of the collapse site, a moraine so aptly named for the town that lies on it. These glacial lakes and moraines disrupted the normal flow patter of most local drainages and creeks. Alluvium is the upper most layer of the surface and is variable in thickness throughout the valley, but normally ranges about fifty feet thick as it is deposited by the Genesee River Valley floodplain (Yager, 2001).

MINE COLLAPSE

The collapse of the Retsof Salt Mine was registered from a local seismic station in Cuylerville, NY (Figure 1) at 5:46 a.m. in conjunction with an earthquake (Richter Magnitude, 3.6). The collapse was a section of shale nearly 500 x 500 in the overlying ceiling that burst causing incredible amounts of groundwater to flow into the open mined cavity deep within the subsurface. The collapse happened in mining room 2-Yard South, located in the southern end of the mine near Cuylerville, NY where at first water from the overlying aquifer was flowing into the mine at nearly 5,000 gallons per minute. This water flow increased up to nearly 20,000 gallons per minute up to a month later (Yager, 2001) or eleven million gallons per day (Kappel, 1999). Failure of the mine was theorized to be anywhere from the new “yielding pillar” mining method to existence of geologic discontinuities/anomalies (Gowan, 2000). Natural gas and hydrogen sulfide concentrations increased as the flooding continued, and in several areas gas flared from wells drilled near the collapse site.

CAUSES OF COLLAPSE

As stated earlier, the causes of the collapse are still debated and uncertain. There are two probable causes that seem most likely given that a section of overlying rock would burst from the ceiling: an event unlikely to be caused by many other theories. The first cause of the collapse, coming from the observed convergence of the ceiling that was produced by overlying brine deposits and the second cause being the new yielding pillar method. The former cause is described by Gowan who states that measured saturation level of brine during the first three days was 100 percent until dropping to 68 percent a few days after (Gowan, 2000). This idea examines that fact that there must have been pre-existing brine source in the overlying bedrock. Brine is water nearly or completely saturated with salt, and in reaction releases H_2 and can form pressure pockets within the reaction zone, which can increase the stress in the overlying rocks. This can increase stress past its threshold and cause a collapse.

The latter cause, the yielding pillar mining method, was a relatively new mining method in the 1990's, which is designed for mining large panels up to sometimes 1,000 feet long. The rooms were 40 foot wide with abutment pillars and smaller 20 x 20 foot pillars. The smaller yielding pillars are designed to deform and transfer the overburden stress load to the side walls of the room. This hypothesis is possible but it is not certain that this method may have been caused the collapse. H. Miller from the University of Missouri says that the collapse was not related to the switch to yielding pillar method.

Convergence of the ceiling surrounding the pillars was observed also with small fractures in the ceiling. Rates of closure increased rapidly in January of 1994. Mining was seized prior in October of 1993 due to a height clearance with a moving machine (Yager, 2001; however, not real preventative steps were taken. Since that point better observations were taken and mining was moved to a different location up until its collapse at which time mining was again shifted to the northern part of the mine.

IMPACTS OF THE RETSOF MINE COLLAPSE

Impacts of the mine collapse were felt all throughout Livingston County and New York State. A major problem associated with the collapse was the drainage of the Genesee Valley aquifer. As the initial collapse triggered the earthquake, the overlying beds were greatly affected in that fractures up through the Silurian and Devonian formations were created. In these linear upward propagations create a “rubble zone”. This rubble zone acts as a channel that allows overhead water down to percolate down and spill out into open cavities that lie beneath. This event was devastating to the Livingston County water supply. With water spilling into the mine at nearly 20,000 gallons a second, the overlying aquifer was greatly reduced.

With a draining of the water supply above the Onondaga Limestone local wells were greatly affected. Most wells to the north section, above and beyond the valley fill aquifer system were relatively unaffected. The lowering of water levels is also known as drawdowns, and was measured in both overlying aquifers, the middle sand and gravel aquifer and the lower bedrock aquifer. The maximum drawdown in the middle aquifer was approximately 250 feet. The maximum drawdown in the lower aquifer was approximately 400 feet near the collapse area drawdowns were measured of 50 feet seven miles north of the collapse site and 110 feet 8 miles south of the collapse. With the lowering of aquifer system, local wells also experienced degradation of water quality. Five screened wells in the lower aquifer system of the Genesee Valley experienced a saline influx in turn making the ground well water inconsumable (Yager, 2001).

In addition to the hydro-geological effects, other potentially significant variables had arisen also. Evaporite formations occur throughout thirty five to forty percent in the underlain United States and are relatively common in the Permian basin in Texas, New Mexico, Oklahoma and Kansas. The formation of two major sinkholes occurred over the collapsed room 2-Yard South and its neighboring room 11-Yard South. The sinkhole above 2-Yard South was previously observed in correlation with the convergence of the ceiling prior to the collapse event. The sinkhole above room 11-Yard South formed shortly after the collapse event due to the surge of water dissolving the pillars that contained the overlying bedrock load from completely caving in on it. These two major sinkholes above rooms 2-Yard South and 11-Yard South have been recorded to have depressed approximately 70 feet. Subsidence in the area is said to have altered surface run-off and smaller creek flow through the area. Beards creek, the closest flowing body of water experienced a change in course due to the subsidence and accumulated small ponds in each of the major sinkholes.

Two other types of subsidence were observed, the first, a normal and usual type of subsidence that is seen over most underground mined areas. This type of subsidence is due to the slow closure of the mine cavity, mining engineer experts believe that due to this type the mine footprint should subside approximately eight or nine feet within the next 200 years but could decrease in rate due to the mining cavity saturated with brine which can support a heavier bed load.

The third type of subsidence observed is caused by the lowering and depletion of ground water levels. This type of subsidence appears to be due to aquifer-system compaction that typically accompanies the depletion of alluvial aquifer-system. With such drastic drops in ground water the underlying aquitard experiences an inelastic compaction that is associated with ground subsidence (Kappel, 1999). Local damages due to collapse and subsidence were observed after the event. Some damages include the loss of State Route 20A which runs through north to south through the Genesee Valley and almost directly over the collapse area in Cuylerville. A small bridge that crosses a small creek was damaged during the event rendering the road not travelable. The bridge was known as Jones Bridge, which so conveniently is located parallel to Jones Bridge Road next to also 20A. State Route 20A along Jones Bridge following the collapse seized traffic for almost three years directing travelers on a short but inconvenient detour. Structural damages to some homes and small business surrounding the collapse site were also experienced along with damage to agricultural lands, public utilities and cultural resources (Kappel, 1999). Figure 6 shows a projected subsidence over the mine footprint, in some cases we can see subsidence up to 8 feet even through residential and commercial areas. These projects are for the next 100 years approximately.

Land subsidence due to underground mining is fairly common especially when we look at coal mining in the Eastern United states such as Pennsylvania and in the Appalachian Mountains. Mathematical models have been presented to better quantify the amount of subsidence we can observe, these models help humans predict the extent of subsidence in an area and can be beneficial to urbanization plans, or human plans for building. The area of subsidence for a horizontal or gently dipping bed after being mined can be estimated to be equal to the surface area of the mined area times one and half the area of that space. This calculation compensates for areas lateral to the mined cavity which is normally along the slope of the subsidence block. This area includes the "angle of influence" which can range between 10 and 45 degrees.

Other problems associated with the collapse were the release of harmful fumes into the air. Hydrogen sulfide and methane gas were emitted in different areas around the collapse. These gases reduced air quality for people in the Livingston County Cuylerville area and also sparked several gas flares in the area. Fortunately the gas flares were slight and relatively harmless creating no major fire disasters.

NOTABLE COLLAPSES IN SALT MINING CAVITIES

Lake Peigneur located near New Orleans, Louisiana was once home to another North American salt mine prior to its collapse in 1980. A group of Texaco oil drillers were probing underneath the 1,300 acre 11 foot deep Lake Peigneur, looking for oil underneath the lake. A pre-existing salt mine located underneath the lake operated as the Diamond Salt Mine. The Texaco drilling company was aware of the salt mine and had planned accordingly; however the disaster seemed unavoidable. As the drill began to submerge, it seized with a loud sound and became stuck, shortly after the drilling crew watched as the five million dollar rig capsized into the lake breaking through the aquitard draining the lake into the open salt mine. At the time workers in the salt mine heard loud bangs and could see knee high muddy water surging into the mine. The alarm was sounded and all 50 miners working that morning escaped with their lives. On the surface of the lake, acting as a drain, the hole in the lake created a whirlpool effect that is sometimes known as the “vortex of doom”. This mine failure and collapse unlike the Retsof Salt Mine was not due to natural causes but human activity and negligence (Bellows, 2008).

Near a local resort in Romania in a town called Ocnele Mari a small roof collapse in a small salt mine terrified local residents and caused damages to houses and a local resort in Ocnele Mari. The mine had been closed in 1992 due to risk of collapse, but a team assembled of Romanian geologists and experts have kept the mine under heavy surveillance in order to protect the mine and local residents. In 2001 a similar event of collapse accrued damages to nearly 60 houses. These collapse events are happening because this is an open cavity that has not been filled with any fluids to relieve stress from the overburden. These events differ from what we see at the Retsof Mine for that very same reason.

REBUILDING A MEMORY

In 2000, American Rock Salt opened a new mine shaft located in between the towns of Geneseo and Mt. Morris, approximately ten miles from the original shaft. The new shaft, now called Hamptons Corners Mine. The American Rock Salt Company founded in 1997 by Joseph Bucci, Gunther Buerman, and Neil Cohen. The completion of this mine shaft signified the first successful salt mine that was constructed post-1960.

The Hamptons Corners Mine brought a reassurance of stability and economy back to Livingston County despite its up and coming major commercial areas, such as Geneseo and Avon. Today American Rock Salt employs over 200 people with hundred of jobs offered in other areas related to the mine, such as transportation and railways. The mining procedure operate in an environmentally conscience effort, by using underground screening and crushing techniques that prevent dust and harmful materials to the surface.

Today the mine produces anywhere between 10,000 and 18.000 tons of rock salt each day. Demand strongly dictates the amount of salt mined each day. The Hamptons Corner mine is currently the number one producer of deicing rock salt in the United States, supplying road salt to twelve different states.

CONCLUSION

Salt is important natural resources that has been used throughout the world dating back to the early Egyptian times as they used it for various types of preservatives in the mummification process. Salt a valuable resource is great for preservatives of different materials and seasonings. Rock salt used for deicing roads has been a somewhat more of a modern technique; however, is an important part of our modern civilizations especially in colder regions that experience heavy snowfall and icing. The northeast United States encounter extremely wicked winters along with every neighboring territory to the north. The loss of the Retsof Salt Mine seemed to be a devastating event in Livingston County economy. The environmental issues mentioned have continued to haunt the Livingston County and the Genesee Valley. The land included in the valley and over the mine footprint will continue to subside as time continues. This subsidence will inevitably cause upcoming and unforeseeable damages in the near future. Ground water levels and quality have increased and regenerated in the past fifteen years however a saline flux of well water is not uncommon. These are just few of the problems and hazards that can be encountered with depending on natural resources deep within the earth. Other cultures have experienced similar if not more devastating disasters in underground mining. In the future these problem like subsidence associated with collapsing, along with ground water trouble will continued to be analyzed. We hope eventually the mining system will stable and these problems will cease and Genesee Valley will continue to be a beautiful place to live.

Figure 1:

Geneseo, New York Quadrangle -7.5 Minute Series Topographic – United States Department of the Interior Geologic Survey.
Cuylerville boxed in black, the town most proximal to the actual collapse felt most of its force. The bridge crossing 20A is also marked; this bridge suffered a collapse itself causing a major traffic detour for almost two and half years

Figure 2:

Leicester, New York Quadrangle -7.5 Minute Series Topographic – United States Department of the Interior Geologic Survey.

This quadrangle shows part of the Genesee Valley through the town of York. The town of York has numerous hamlets, Retsof, Greigsville and others. The black box is the approximate location of the original mine shaft prior to its relocation to Hamptons Corners.

Figure 3:

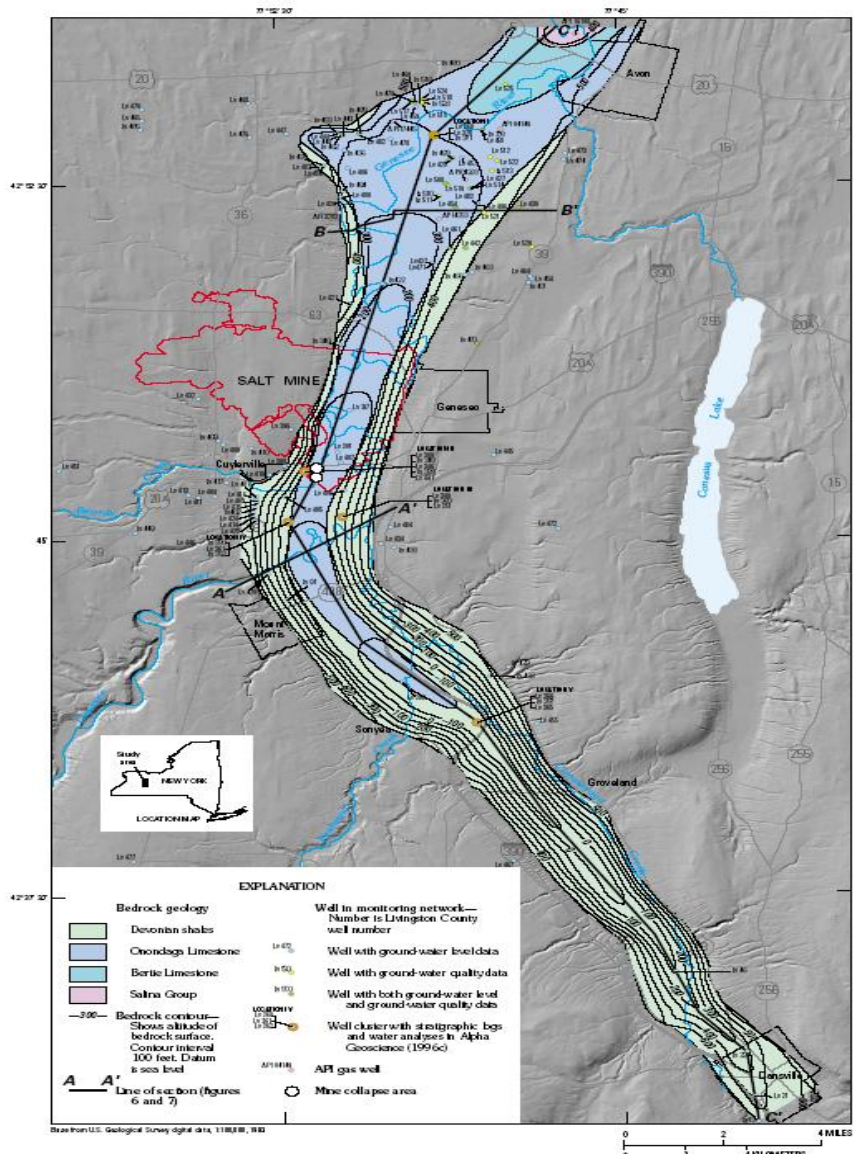

Figure 3 shows a geologic section of the Genesee Valley. The mine is outlined in the Red and cross sections were made from line A-A'.

Taken from Simulated Effects of Salt-Mine Collapse on Ground-Water Flow and Land Subsidence in a Glacial Aquifer System, Livingston County, New York By Richard M. Yager, Todd S. Miller, and William M. Kappel Professional Paper 1611

Figure 4:

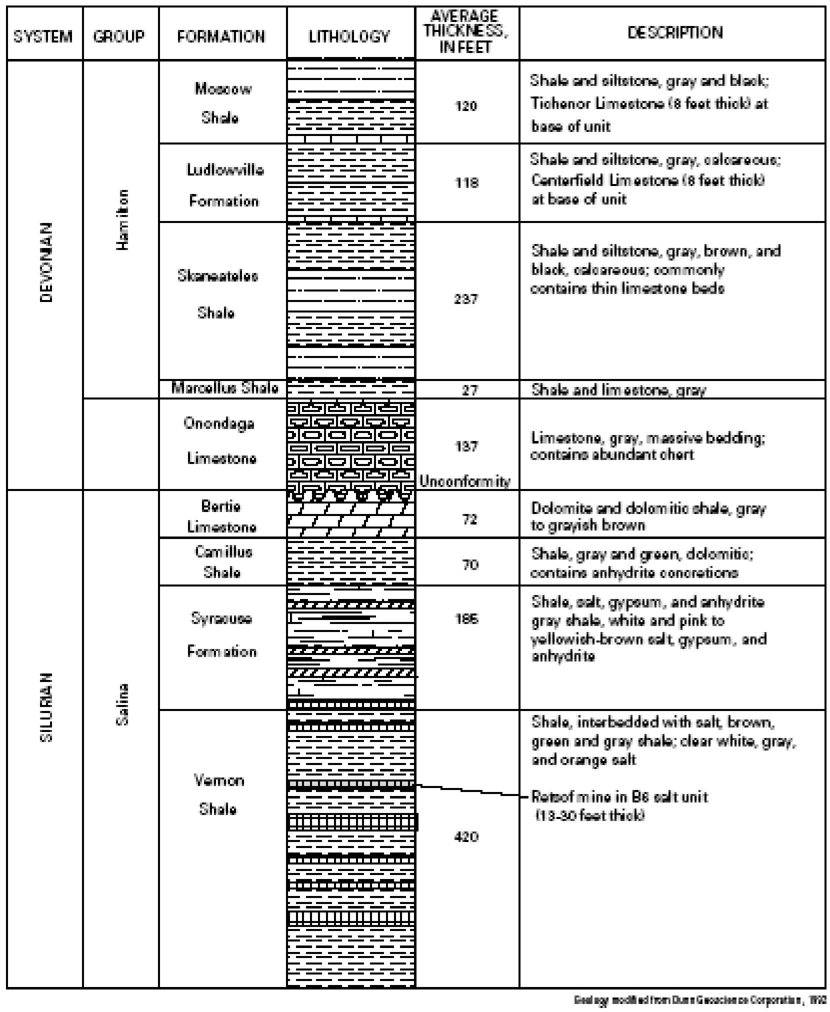

Figure 5. Generalized columnar geologic section of Paleozoic rocks in Retsof salt mine vicinity, Livingston County, N.Y.

Figure 2 shows a detailed stratigraphic section that occupies the Genesee Valley. Relative thicknesses of each unit are defined along with characteristics of the beds. This section does exclude the glacial and alluvial units that overlie the bedrock.

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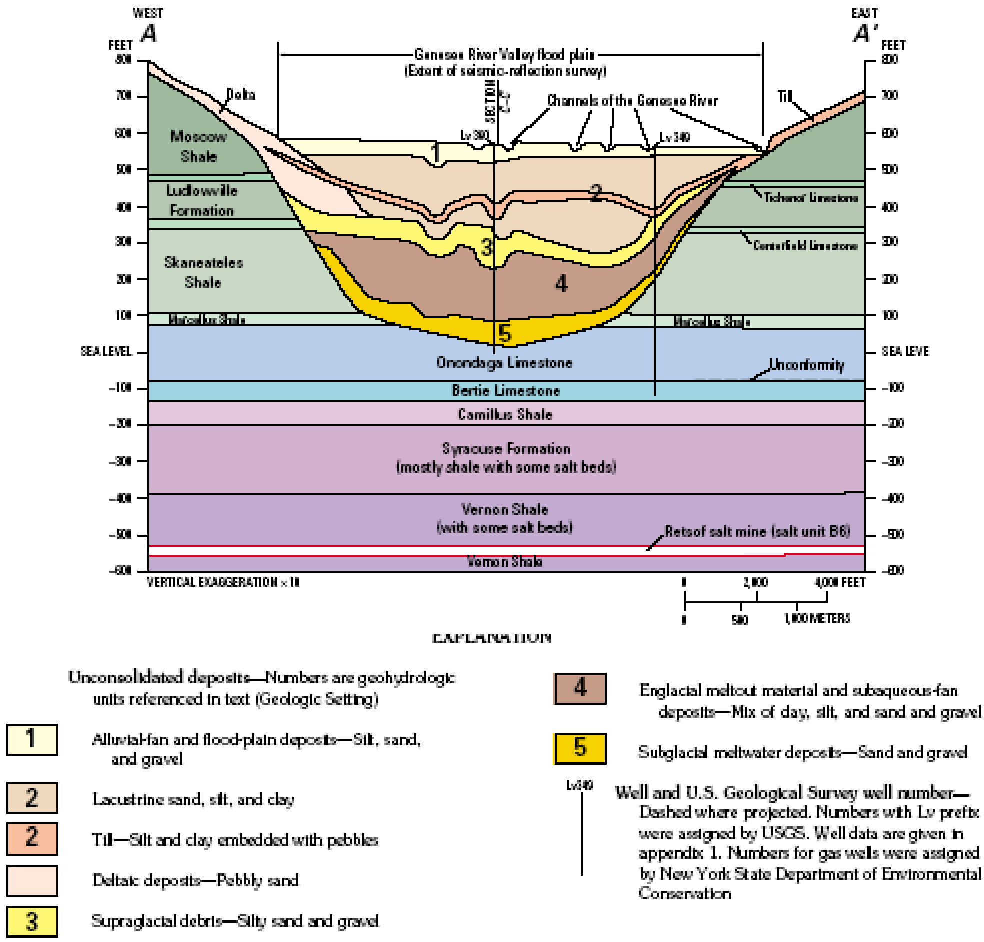
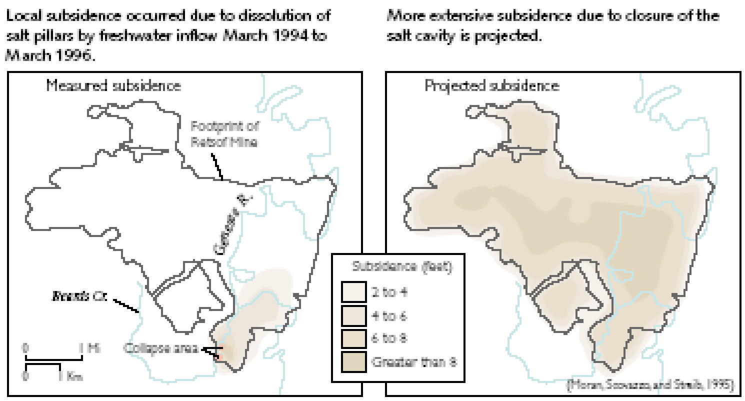


Figure 3 is shows a relative cross-section taken from Figure 1 along the line A-A' through the Genesee Valley. Here we can see a somewhat more detailed analysis of the valley fill materials that make up most of the Genesee Valley.

Taken from Simulated Effects of Salt-Mine Collapse on Ground-Water Flow and Land Subsidence in a Glacial Aquifer System, Livingston County, New York By Richard M. Yager, Todd S. Miller, and William M. Kappel Professional Paper 1611

Figure 6:



This map shows the footprint of the Retsof Salt Mine located in the Genesee Valley and its subsidence observed from 1994 to 1996 on the left. The footprint on the right shows a projected subsidence above the mine over the next century approximately. As we can see the subsidence engulfs the entire mine, an approximate area of 6,000 square acres. As the land continues to sink, it will eventually cause damages to local houses and business' in the area.

Taken from Land Subsidence in the United States: The Retsof Salt Mine Collapse, U.S. Geological Survey by William Kappel, Richard Yager and Todd Miller.

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